APPLICATION FOR LETTERS PATENT

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FOR

INTENSIFIED HYBRID SOLID-STATE SENSOR

INTENSIFIED HYBRID SOLID-STATE SENSOR

FIELD OF THE INVENTION

The present invention is directed to an intensified hybrid solid-state sensor. More particularly, the present invention relates to an image intensifier using a CMOS or CCD sensing device connected in close physical proximity to a microchannel plate (MCP) and photo cathode.

BACKGROUND OF THE INVENTION

The present invention relates to the field of image intensifying devices using solid-state sensors, such as a CMOS or CCD device. Image intensifier devices are used to amplify low intensity light or convert non-visible light into readily viewable images. Image intensifier devices are particularly useful for providing images from infrared light and have many industrial and military applications. For example, image intensifier tubes are used for enhancing the night vision of aviators, for photographing astronomical bodies and for providing night vision to sufferers of retinitis pigmentosa (night blindness).

There are three types of known image intensifying devices in prior art; image intensifier tubes for cameras, all solid-state CMOS and CCD sensors, and hybrid EBCCD/CMOS (Electronic Bombarded CCD or CMOS sensor).

Image intensifier tubes are well known and used throughout many industries. Referring to FIG. 1, a current state of the prior art Generation III (GEN III) image intensifier tube 10 is shown. Examples of the use of such a GEN III image intensifier tube in the prior art are exemplified in U.S. Pat. No. 5,029,963 to Naselli, et al., entitled REPLACEMENT DEVICE FOR A DRIVER'S VIEWER and U.S. Pat. No. 5,084,780 to Phillips, entitled TELESCOPIC SIGHT FOR DAYLIGHT VIEWING. The GEN III image intensifier tube 10 shown, and in both cited references, is of the type currently manufactured by ITT Corporation, the assignee herein. In the intensifier tube 10 shown in

Fig. 1, infrared energy impinges upon a photo cathode 12. The photo cathode 12 is comprised of a glass faceplate 14 coated on one side with an antireflection layer 16, a gallium aluminum arsenide (GaAlAs) window layer 17 and gallium arsenide (GaAs) active layer 18. Infrared energy is absorbed in GaAs active layer 18 thereby resulting in the generation of electron/hole pairs. The produced electrons are then emitted into the vacuum housing 22 through a negative electron affinity (NEA) coating 20 present on the GaAs active layer 18.

A microchannel plate (MCP) 24 is positioned within the vacuum housing 22, adjacent the NEA coating 20 of the photo cathode 12. Conventionally, the MCP 24 is made of glass having a conductive input surface 26 and a conductive output surface 28. Once electrons exit the photo cathode 12, the electrons are accelerated toward the input surface 26 of the MCP 24 by a difference in potential between the input surface 26 and the photo cathode 12 of approximately 300 to 900 volts. As the electrons bombard the input surface 26 of the MCP 24, secondary electrons are generated within the MCP 24. The MCP 24 may generate several hundred electrons for each electron entering the input surface 26. The MCP 24 is subjected to a difference in potential between the input surface 26 and the output surface 28, which is typically about 1100 volts, whereby the potential difference enables electron multiplication.

As the multiplied electrons exit the MCP 24, the electrons are accelerated through the vacuum housing 22 toward the phosphor screen 30 by the difference in potential between the phosphor screen 30 and the output surface 28 of approximately 4200 volts. As the electrons impinge upon the phosphor screen 30, many photons are produced per electron. The photons create the output image for the image intensifier tube 10 on the output surface 28 of the optical inverter element 31.

Image intensifiers such as those illustrated in Fig. 1 have advantages over other forms of image intensifiers. First, intensifiers have a logarithmic gain curve. That is, the

gain decreases as the input light level is increased. This matches the human eye response particularly when bright lights are in the same scene as low lights. Most solid-state devices have a linear response; i.e., the brighter the light the brighter the output signal. The result is that bright lights appear much brighter to a viewer of a solid-state system and tend to wash out the scene. Solid-state sensors can be modified to produce a gain decrease as input light is increased, however, this requires changing the amplifier gain, using shuttering, or using anti-blooming control.

Another advantage of image intensifiers is the ability to function over a large range of input light levels. The power supply can control the cathode voltage and thereby change the tube gain to fit the scene. Thus tubes can function from overcast starlight to daytime conditions.

However, image intensifier/I^2 cameras suffer from numerous disadvantages. The electron optics of the phosphor screen produces a low contrast image. This results in the object looking fuzzier to the human observer, or solid-state sensor, when viewed through an image intensifier. Although this deficiency has been somewhat reduced with further image intensifier development, solid-state imagers generally have better performance.

Another disadvantage with image intensifier/I^2 cameras is "halo." Halo results from electrons being reflected off either the MCP or the screen. The reflected electrons are then amplified and converted into light in the form of a ring around the original image. In image tubes, the halo from electrons reflected from the MCP has been reduced to a negligible effect for the most recent production tubes. However, the halo from the screen section still exists, although not to the degree of the cathode halo. Nevertheless, the screen halo is still a significant defect in imaging systems when a CCD or CMOS array is coupled to the image intensifier. This is because these arrays are more sensitive than the eye to the low light levels in the screen halo.

Another disadvantage is that image intensifiers do not have a method of providing electronic read-out. Electronic read-out is desired so that imagery from thermal sensors may be combined with intensified imagery with the result that the information from both spectra will be viewed at the same time. One solution has been to create an I^2 camera by coupling a CCD or CMOS array to an image intensifier tube. When a solid-state device is coupled to an image tube the resultant camera has all performance defects of the image tube that is low contrast, often poor limiting resolution due to coupling inefficiencies and the added cost of the image tube to the camera.

Solid-state devices typically include CCD or CMOS sensors. They function by directly detecting the light, electronically transferring the signal to solid-state amplifiers, then displaying the image on either a television type tube or display such as a liquid crystal display. Figs. 2a and 2b illustrate a flow chart and schematic diagram for a typical CCD sensor.

CCD and CMOS sensors are solid-state devices; that is, there is no vacuum envelope and the output is an electronic signal that must be displayed elsewhere and not within the sensor. The solid-state devices operate with power of 5-15 volts. The light is detected in individual pixels as labeled "s" and translated into electrons that are stored in the pixel until the pixel is read out to the storage register. From the storage register the electronic information contained in multiple pixels is then transferred to a read out register and then to output amplifiers and then to a video display device such as a cathode ray tube.

The disadvantages of an all solid-state device are poor low light level performance, potential blooming from bright light sources, poor limiting resolution, and high power consumption. The poor low light performance is due to dark current and read-out noise resulting in low signal-noise ratios. If a signal gain mechanism were provided prior to read-out this issue would be negated, as sufficient signal would exist to overcome

the noise sources. Solid-state device architectures usually do not permit an amplification
section prior to read-out. The poor limiting resolution is due to large pixel sizes usually
chosen in an attempt to collect a large signal and thereby increase the signal to noise
ration. These disadvantages have effectively prevented the use of solid-state sensors in

5   night vision applications. The advantages of solid-state devices are better image contrast
as compared to the image intensifier/I^2 camera, the availability of electronic read-out, and
lower cost, particularly when the solid-state sensor is a CMOS array.

As can be seen, the strengths and weaknesses of image intensifiers and solid-state

10   sensors compliment each other and theoretically a combination of both devices would
give better performance. One such combination proposed as an alternative to image
intensifiers/ I^2 cameras and solid-state sensors, is the electron bombarded CCD/CMOS
sensor (EBCCD/CMOS). This device consists of the photo-cathode and body envelope of
the image tube, and either a CCD or CMOS sensor integrated into this envelope. An

15   illustrative example of an EBCCD/CMOS sensor is shown in FIG. 3. A high voltage is
applied between the cathode and solid-state sensor so that the resulting electrons are
amplified within the silicon in the solid-state sensor by electron bombardment.

The advantages of the EBCCD/CMOS device are that it provides electronic read-

20   out. But the disadvantages are numerous. First, the intra-scene dynamic range is
compressed. This means that overall contrast within the scene, when bright objects are
next to dark objects, is reduced compared to an image intensifier/I^2 camera and all solid-
state device. Secondly, the sensor suffers "halo" degradation of the image around bright
lights due to electrons reflected off of the solid-state sensor. This halo exists in regular

25   image tubes; however, technological improvements have reduced the halo to the point of
non-existence. Thirdly, the very high voltage required to operate the device (2-10 kV)
damages the silicon surface causing decay in performance over time.

Therefore, it is an object of the present invention to provide an intensified hybrid solid-state sensor that combines the functions of the image intensifier, good signal-to-noise ratio and high logarithmic gain, with the electronic read-out functions either of a complementary Metal Oxide Semiconductor (CMOS) or charged coupled device (CCD).

SUMMARY OF THE INVENTION

The present invention provides an intensified hybrid solid-state sensor. The solid-state sensor, according to the present invention, includes an imaging device comprising a solid-state sensor assembled with an image intensifier cathode, microchannel plate (MCP), and body envelope. This device combines the best functions of the image intensifier, good signal-to-noise ratio and high logarithmic gain, with the electronic read-out functions either of a complementary Metal Oxide Semiconductor (CMOS) or charged coupled device (CCD). Applications for this invention are primarily night vision systems where good low light sensitivity and high gain are required.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention will become more clearly understood it will be disclosed in greater detail with reference to the accompanying drawings, in which:

Figure 1 is a schematic illustration of a typical image intensifying tube;

Figure 2A is flow chart for a typical CCD sensor;

Figure 2B is a schematic diagram of a typical CCD imaging surface;

Figure 3 is a cross-sectional view of a typical Electron Bombarded CCD device;

Figure 4A is a cross-sectional view of an intensified hybrid solid-state sensor according to the present invention;

Figure 4B is a schematic representation of an intensified hybrid solid-state sensor according to the present invention;

Figure 5A is a schematic illustration of a microchannel plate (MCP) and a back thinned CCD for use in the present invention;

Figure 5B is a schematic illustration of a microchannel plate (MCP) and a standard CCD for use in the present invention;

Figure 5C is a perspective view of a CMOS-type image sensor for use with the present invention;

5   Figure 6A is a perspective view of MCP channels having round profiles and a CMOS well;

Figure 6B is a perspective view of MCP channels having square profiles and a CMOS well;

Figure 7A is a schematic top view of a large pixel/small MCP channel pitch per

10   unit area of the sensor surface according to the present invention;

Figure 7B is a schematic top view of a one-to-one pixel to MCP channel per unit area of the sensor surface according to the present invention

Figure 7C is a schematic top view of a small CMOS pixel pitch/large MCP channel per unit area of the sensor surface according to the invention;

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DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 4B is a schematic representation of an intensified hybrid solid-state sensor device 41 according to the present invention. Sensor 41 comprises a standard image tube photo cathode 54, a microchannel plate (MCP) 53 and a solid-state imaging sensor 56.

20   Solid-state imaging sensor 56 can be any type of solid-state imaging sensor. Preferably, solid-state imaging sensor 56 is a CCD device. More preferably, solid-state imaging sensor 56 is a CMOS imaging sensor. Fig. 5A illustrates a back-thinned CCD imaging device as imaging sensor 56'. In this embodiment, MCP 53 is connected with a back thinned CCD sensor 56'. Back-thinned CCD 56' includes an electron receiving surface,

25   such as diffusion collection area 56a' and a readout area 62. Fig. 5B illustrates an alternative standard CCD imaging device including MCP 53 connected to a standard CCD 56''. CCD 56'' includes an oxide cover 63 and plurality of collection wells 64. Fig. 5C illustrates sensor 56 as a CMOS sensor, including a CMOS substrate 56''' and a plurality of collection wells 65.

For various reasons, CCD based image sensors are limited or impractical for use in many applications. First, CCDs require at least two polysilicon layers with a buried-channel implant to achieve their high performance, meaning that they cannot be fabricated using standard CMOS fabrication processes. Second, the level of integration that can be achieved with CCD based imagers is low since they cannot include the devices necessary to integrate them with other devices in an application. Finally, the circuits used to transfer data out of the image array to other devices on the system board, such as Digital Signal Processors (DSPs) and other image processing circuits, have a large capacitance and require voltages higher than the other circuits. Since the currents associated with charging and discharging these capacitors are usually significant, a CCD imager is not particularly well suited for portable or battery operated applications.

As such, less expensive image sensors fabricated out of integrated circuits using standard CMOS processes are desirable. Essentially, with a CMOS type imager sensor, a photo diode, phototransistor or other similar device is employed as a light-detecting element. The output of the light-detecting element is an analog signal whose magnitude is approximately proportional to the amount of light received by the element. CMOS imagers are preferred in some applications since they use less power, have lower fabrication costs and offer higher system integration compared to imagers made with CCD processes. Moreover, CMOS imagers have the added advantages that they can be manufactured using processes similar to those commonly used to manufacture logic transistors. While the preferred embodiment of the invention incorporates a CMOS sensor as the imaging sensor 56, any solid-state imaging sensor would work and is within the scope of this patent.

Referring again to Fig. 4B, photo cathode 54 can be a standard photo cathode as used in any known type of image intensifying device. Photo cathode 54 can be, but is not limited to, a material such a GaAs, Bialkali, InGaAs, and the like. Photo cathode 54 includes an input side 54a and an output side 54b. MCP 53 can be, but is not limited to a

silicon or glass material, and is preferably about 10 to 25 mm thick. MCP 53 has a plurality of channels 52 formed between an input surface 49 and output surface 50. Channels 52 can have any type of profile, for example a round profile 52' (Fig. 6A) or a square profile 52'' (Fig. 6A.) MCP 53 is connected to electron receiving surface 56a of imaging sensor 56.

Preferably, output surface 50 of MCP 53 is physically in contact with electron receiving surface 56a of imaging sensor 56. However, insulation may be necessary between MCP 53 and imaging sensor 56. Accordingly, a thin insulating spacer 55 may be inserted between output surface 50 of MCP 53 and electron receiving surface 56a of imaging sensor 56. Insulating spacer 55 can be made of any electrical insulating material and is preferably formed as a thin layer, no more than several microns thick, deposited over electron receiving surface 56a of imaging sensor 56. For example, insulating spacer may be, but is not limited to, an approximately 10μm thick film Alternatively, insulating spacer 55 could be a film formed on the output surface 50 of MCP 53 (not shown).

CMOS imaging sensor 56 includes electron receiving surface 56a and output 56b. The increased number of electrons 48 emitted from MCP 53 strike electron receiving surface 56a. Electron receiving surface 56a comprises a CMOS substrate 56''' and a plurality of collection wells 65 (Fig. 5C). Electrons 48 (See Fig. 4B) collected in collection wells 65 are processed using standard signal processing equipment for CMOS sensors to produce an intensified image signal that is sent through output 56b to an image display device 46.

An electric biasing circuit 44 provides a biasing current to sensor 41. Electric biasing circuit 44 includes a first electrical connection 42 and a second electrical connection 43. First electrical connection 42 provides a biasing voltage between photo cathode 54 and MCP 53. The biasing voltage from first electrical connection 42 is preferably set so as to be less than the biasing voltage than the EBCCD/CMOS sensor

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cathode to CCD voltage, i.e., 2-10 kV. For example, one preferred biasing voltage could be similar to that of image tubes, such as ~1400V. Second electrical connection 43 applies a biasing voltage of between MCP 53 and CMOS sensor 56. Preferably, the biasing voltage applied through second electrical connection 43 is significantly less than

5   the image tube - screen voltage of about 4200V of the prior art devices (Fig 1). For example, the biasing voltage applied through second electrical connection 43 could be, but is not limited to ~100V. Fig. 4A illustrates one potential configuration of the sensor 41. In this configuration, photo cathode 54, MCP 53, and imaging sensor 56 are maintained in a vacuum body or envelope 61 as a single unit, in close physical proximity

10   to each other.

Referring to Fig. 4B, in operation, light 58, 59 from an image 57 enters intensified hybrid solid-state sensor 41 through input side 54a of photo cathode 54. Photo cathode 54 changes the entering light into electrons 48, which are output from output side 54b of

15   photo cathode 54. Electrons 48 exiting photo cathode 54 enter channels 52 through input surface 49 of MCP 53. After electrons 48 bombard input surface 49 of MCP 53, secondary electrons are generated within the plurality of channels 52 of MCP 53. MCP 53 may generate several hundred electrons in each of channels 52 for each electron entering through input surface 49. Thus, the number of electrons 47 exiting channels 52

20   is significantly greater than the number of electrons 48 that entered channels 52. The intensified number of electrons 47 exit channels 52 through output side 50 of MCP 53, and strike electron receiving surface 56a of CMOS imaging device 56.

Fig. 6 illustrates how the increased number of electrons 47 exit channels 52 and

25   strike a particular collection well 65' of CMOS imaging sensor 56. As can be seen from this illustration, a relationship exists between the collection wells 65' and the number of channels 52 which emit electrons 47. In general, adjacent channels 52 of MCP 53 are separated by a predetermined channel pitch 52a. Fig. 6 illustrates a channel pitch 52a that results in more than one channel 52 per collection well 65'.

Figures 7A-7C illustrate three different alternatives of CMOS well/channel pitch relationships according to the invention. Fig. 7A illustrates one relationship between channel pitch 52a and a CMOS collection well 65'. In this case, channel pitch 52a is relatively small, while the size of CMOS well 65' is relatively large. This permits several electrons 47 from two or more channels 52 to strike CMOS collection well 65'. Fig. 7B illustrates another CMOS well/channel pitch relationship. In this embodiment, channel pitch 52a and the size of CMOS collection well 65' are approximately in a one-to-one relationship. As such electrons 47' from a single channel 52 strike a single collection well 65'. Fig. 7c illustrates another CMOS well/channel pitch relationship where channel pitch 52a is relatively large and the size of CMOS collection well 66 is relatively small. In this case electrons 47'' from a single channel 52 strike multiple collection wells 66. While each of these structures provide various advantages, the relationship illustrated in Fig. 7A is preferred for the present invention.

As a result, the intensified hybrid solid-state sensor operates in different conditions than any of the other prior art concepts. The result is that the MCP 53 can be mounted directly on the CMOS sensor 56 giving the hybrid device similar contrast to the all solid-state device but with low halo, good signal-to-noise ratio, and logarithmic gain of the image tube. Since operating voltages are lower, the hybrid device can be gated like an image tube allowing operation from overcast starlight condition to daytime operation. The hybrid sensor has better halo from the lack of physical gap between MCP 53 and CMOS sensor 56. This lack of physical separation in the two components is also why contrast is improved when compared to the EBCCD/CMOS or image intensified camera. The hybrid device also has the logarithmic gain curve of the image tube. Unlike the EBCCD/CMOS sensor, the hybrid sensor can be gated due to the low cathode voltages.

The above detailed description of a preferred embodiment of the invention sets forth the best mode contemplated by the inventor for carrying out the invention at the time of filing this application and is provided by way of example and not as a limitation. Accordingly, various modifications and variations obvious to a person of ordinary skill in the art to which it pertains are deemed to lie within the scope and spirit of the invention as set forth in the following claims.

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